Exhibit Columns 15-P, Mines Department World's Columbian Exposition, Chicago, Ill.

Reprinted from the Journal
OF THE
SOCIETY OF CHEMICAL INDUSTRY
March 31st, 1890.

THE
MacArthur-Forrest Process
OF
Gold Extraction

BY
J. S. MACARTHUR.

PRESENTED BY
The Gold and Silver Extraction, Mining and Milling Company,

Rooms 8, 9 and 10,
Tabor Grand Opera House Block,
DENVER, COLORADO.

THE APP-STOTT PRINTING CO., DENVER.

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Reprinted from the Journal of the Society of Chemical Industry,
March 31, 1890. No. 3. Vol. IX.

THE MACARTHUR-FORREST PROCESS OF GOLD EXTRACTION.

BY J. S. MACARTHUR.

In order to understand the present systems of gold extraction, to properly appreciate the work already done, and to gauge the difficulties to be surmounted, it is necessary for us to look back and trace the connection between the known forms of gold as found in nature and the methods used to separate it from its base environments.

In the earliest ages gold would naturally only be found in nuggets and grains (our word carat is derived from a Persian word meaning a grain), which required no means of separation beyond picking up —happy age when gold had only to be picked up !

From grains the ancient would come down to gold dust, and this was no doubt separated from the sand or earthy matter with which it was associated, by the skilful use of air currents which were caused to blow away the sand, leaving the precious metallic dust. This method is still practiced in Arabia and the East. Wherever water was plentiful it was found that it did the required separation better and more economically than air, a method of separation which has been and still is in use everywhere all over the world. The prospector, digger, explorer, and even the tourist nowadays provides himself a "pan" in which to wash a sample of "dirt" at the nearest stream. From the pan comes the "cradle," "long tom," and the innumerable mechanical arrangements for the separation of gold from earthy matters. Up to this point we have only mechanical means of separation which depend on the high specific gravity of gold compared with sand, clay, etc., but at this stage in the evolution of gold extraction we find the first move made towards a chemical method. When there was a lot of rich dirt in his pan the digger found it very difficult to wash away the last of the sand without losing a large proportion of the finely divided gold, so he hit on the expedient of pouring in a little mercury, which formed a heavy, massive, though fluid alloy with the gold, making the separation of the last portions of the light granular sand a very easy matter. This plan is still in world-wide use alike by the solitary digger who lives in a lonely canon, and by the well-organized company that "hydraulics" 1,000 tons of "pay dirt" per day.

Let us now look at the present state of the gold industry. Let us imagine a digger who has exhausted all the gravel and pay-dirt in the canon or gully ; he travels up the gully looking to the right hand and to the left for traces of the precious metal; occasionally he finds a piece of gold-bearing rock and is led on and on till he finds the source of these auriferous stones to be a reef. Now begins gold-mining proper. A shaft is sunk on the reef or a tunnel driven into it and great masses of rock are brought to the surface, and naturally the miner is led to imitate nature by crushing this rock to a fine sand and then he modifies the treatment formerly given to alluvial deposits to adapt it to the new circumstances. The ore, immediately on being crushed to powder (which is generally done by huge gravitation stamps), is carried over an amalgamated copper plate by a stream of water. In passing over the amalgamated plate the gold is caught by the mercury, while the sand, now called tailings, is washed off. The gold is recovered by scraping the amalgam off the copper plate at stated intervals, generally once a month, when by distillation the mercury is recovered as well as the gold separated. If all the gold the ore contained existed in the heavy metallic form the recovery by this method would be complete and the loss *nil;* but the tailings are frequently found to contain a little gold, and on close examination particles of pyrites and sulphides of the various base metals are found diffused through the mass. When these metaliferous particles are separated from the mass of tailings, it is found that they principally contain the gold, so that it is now usual in practice to pass the tailings through some form of concentrating machinery, of which the well-known Frue-vanner is a good example, whereby the pyrites and other sulphides are retained in virtue of their higher specific gravity and the sand washed away. The rich proportion now called "concentrates" may contain up to twenty oz. of gold per ton, though four or five ounces is much nearer the average figure.

If the concentrates are examined closely, even microscopically, no free gold can be distinguished, and if they be treated with mercury they will yield to it little or none of their gold contents. Sometimes a considerable portion of gold may be got from them by a long continued grinding in cast-iron pans in presence of mercury; this grinding seems to force the sulphur and base metals as well as the gold into combination with the mercury, so that the bullion got from the amalgam often contains over 95 per cent. of copper, lead, and other base metals, while there is a corresponding loss of mercury, which is carried away partly as sulphide and partly in a "floured state"—the flouring is caused by the small globules of mercury being coated with a film of sulphide of mercury, which prevents the particles coalescing. Thus there is a double loss: chemical, by the formation of sulphide of mercury, and mechanical, by flouring. This loss is so well known that concentrates are only treated by this form of amalgamation in localities where nature forbids any more elaborate process. Sometimes the amount of loss may be lessened by roasting the concentrates before amalgamation, but this is by no means a perfect remedy, as the roasting removes only volatile constituents of the concentrates, principally sulphur, while the base metals—lead, zinc, etc.—are left in the form of oxide to oxidize and waste their equivalent of mercury. Attempts have also been made to decrease the loss of mercury and increase the yield of gold by adding to the contents of the pan all sorts of chemicals to "doctor" the "sickened"—that is, floured mercury. These chemicals are generally mixtures of sulphate of iron, sulphate of copper, salt, lime, soda, etc. This kind of "doctoring" may be effective in some cases, but it is seldom practiced with intelligence. Where the percentage of concentrates is limited, and where there are a number of mines, it is common for some enterprising man to set up a smelting or chlorination work which is made large enough to deal with the concentrates of the district. I will not take time to describe the various processes of smelting, nor could it be done at any evening sederunt, but we may bear in mind that all smelting processes end in alloying the gold with lead, and cupelling in the usual way with which we are all familiar. Because of the obvious impracticability of smelting, requiring well-built brick furnaces, coal, fluxes, etc., at the typical gold mine high up on the mountain range, possibly near or beyond the timber line, chlorination is much more commonly practiced and consequently merits a full description. In giving this description, I will confine myself chiefly to the old standard Plattner process as I have seen it practiced in California, where timber is abundant and cheap.

The first and essential operation prior to chlorination proper is roasting. It is obvious that a mixture of sulphides and arsenides of iron, copper, lead, zinc, and metals generally will absorb an almost unlimited amount of chlorine, so that the small proportion of gold present would fare badly in a general scramble of the molecules for chlorine. That the metals may have the least opportunity to combine with chlorine, the sulphur is expelled and their affinities satisfied as far as possible with oxygen by roasting. The roasting is generally done in a large reverberatory furnace, that has no very noteworthy feature in its construction. The concentrates are charged into the furnace at the cold end, heated very gradually, continually stirred and slowly worked forward into the hottest part, care being taken to admit air freely during the whole operation. Where chlorination is practiced on the most extensive scale, this roasting generally takes about 24 hours, and consumes from a minimum of half a cord to a cord of wood per ton, roasted. (A cord of wood gives about as much heat as a ton of coal.) It is a common saying that the success of chlorination depends more on the furnaceman than on the chlorinator, and on looking into hard chemical facts we find that this is really the case, for if only one-half per cent. of iron were left unoxidized it would absorb nearly 1 per cent. of chlorine, equal to about 3 per cent. of bleaching-powder, and all this before the gold gets a single molecule of chlorine. Towards the end of the roasting, and about 15 or 30 minutes before the ore is discharged from the furnace, it is usual to stir in a small proportion of common salt. The object of this is to satisfy with chlorine as far as possible, copper, zinc, and other metals whose oxides have a tendency to form chlorides when they get chlorine presented to them in the free state. This chloridizing device is, however, only partially effective, as the chlorides formed are apt to be immediately decomposed under the influence of hot air, and in the case of lead the oxide or sulphate will not combine with chlorine in the furnace, but combines with it readily when offered moist and at the ordinary atmosphere temperature. The roasted and oxidized ore is now sprinkled with water to make it slightly moist, and is then charged into a wooden vat having a perforated false bottom. The chlorine, generated at an outside source, is led in between the true and false bottom, and gradually permeates upwards through the mass of the porous ore. The small amount of water held by the ore then becomes a saturated solution of chlorine, which gradually acts on the gold, so that in the course of one or two days it may be washed out as the soluble chloride by a further amount of water. This weak solution of chloride of gold is run into a tank, a solution of ferrous sulphate added, precipitate of gold allowed to settle for 48 hours if possible, and the supernatent solution allowed to flow off. When sufficient gold precipitate has accumulated, it is collected and run into bars. Besides the Plattner form of chlorination which I have described, there are others which vary from Plattner and among themselves in the manner of application of the chlorine—most of them using revolving barrels instead of open vats for the chlorination proper.

The best known of these are :—

The Mear's process, where chlorine is used under its own gaseous pressure.

The Newbery-Vautin, where air pressure is used.

The Pollok, recently described before this Section of the Society, where hydraulic pressure is used, and

The Theis, where the chloronation is done in a barrel without any pressure, as described in this Journal, 1889, 895.

Let us now return to the mine. The deeper we sink down into the reef, we find that while the richness of the ore may remain constant, the proportion of free gold, that is, amalgamable gold, becomes smaller and smaller, while the proportion of gold-bearing sulphides becomes greater and greater till we come to the water level, where it often happens that the free gold leaves entirely and becomes wholly refractory, that is, non-amalgamable. The water level is generally regarded as the point where atmospheric and weather influences cease, and that down to that point the rain water has penetrated and gradually washed away the oxidisable base metals, leaving the inert gold in the crevices of the equally inert quartz, whereas the ore found below the water level, not having been subjected to oxidizing influences, retains all its metals untouched and unchanged.

An interesting problem now presents itself:—An ore consisting of a complex mixture of silica and the various compounds of iron, copper, lead, zinc, antimony, arsenic, and sulphur (for convenience I will include all these compounds under the general term sulphides) and gold in the proportion of 10,000 parts of silica and sulphides to one part of gold, is very much richer than the average auriferous ore, and the question is how can we best separate the one from the ten thousand. Under favorable circumstances the gold and the useful metals may be recovered by smelting, but these favorable circumstances, which are proximity of the gold mine to coal, clay, limestone and other fluxes, are quite exceptional, as auriferous reefs are generally found in primary formations. As before implied, chlorination is frequently inapplicable—no attempt is ever made to chlorinate gold ore containing an appreciable quantity of lead—and where applicable is always troublesome and never cheap. When this question presented itself to Dr. Forrest and myself, we tried to find some solvent which, unlike chlorine and mercury, would have a stronger affinity for gold than for sulphides. Acting on this principle we drew out a list of all probable or possible solvents fulfilling this condition. This list includes cyanides, and we found that these salts solved the problem

Our experiments were conducted first on a small scale, and on ores of all kinds and from all mines in all parts of the world. The result of these small trials was so satisfactory that we gradually worked from less to more, and in no long time larger quantities were worked, and now the process is in or on the eve of being put in operation in all quarters of the globe. I have now much pleasure in describing the method of working most generally applicable. The ore is ground to about the fineness of sea sand. If instead of ore we are working tailings from the amalgamation process, these are generally not to be re-ground, but treated as delivered. The finely divided material is mixed with a solution of a cyanide, say cyanide of potassium, containing on an average 0.4 per cent. of cyanogen as the cyanide of potassium or other alkali or akaline earth. The ore and solution are stirred together for about six hours, more or less, this being the average time required to dissolve the gold; in practice the time required is determined by direct experiment. When the gold is known to be dissolved, the pulp is discharged into an ordinary filtering tank, where the filteration may, if necessary, be assisted by suction, and where the ore is washed by water or by the waste cyanide solution from a previous operation. The ore, after treatment with cyanide solution, is unchanged to the eye, as almost nothing but the imperceptible proportion of gold present has been removed. The gold now being in solution, the next object is to get it precipitated, and here we encounter a serious difficulty. Gold and cyanogen have such a strong mutual affinity, that it is difficult to get any substance that will separate them. The gold cannot be precipitated by any ordinary method, such as the use of ferrous sulphate or oxalic acid; even sulphuretted hydrogen and sulphide of sodium will not precipitate gold from its cyanide solution, though they precipitate silver. On referring to books on electro-gilding, we got no assistance, as the invariable method given for the recovery of gold from cyanide solutions was evaporate to dryness and fuse the residue. We had noticed, however, by experiment, that zinc precipitated gold very feebly, and tried this in the same way that copper is precipitated from its ordinary solutions by scrap iron, but scrap zinc had no effect; then granulated zinc was tried, with a most imperfect and disappointing result: then heating in presence of scrap and granlated zinc, but this had only the effect of forming urea, and assisting the precipitation very little indeed. Further, we tried zinc dust, but still there was no success; finally we prepared some zinc in a form like sawdust, porus and with a large surface of bright metal. On allowing the cyanide of gold solution to trickle through a mass of the zinc, we found that it trickled out gold-free, and, better still, we found that the action became more vigorous and pronounced after a portion of the gold had been precipitated on it, doubtless as gold and zinc formed together a more powerful electro-chemical precipitant than zinc by itself. An arrangement of a porous mass of zinc like a sponge formed a chemical filter, which at once precipitated and collected the precious metal; indeed, so like an ordinary water purifying device was this zinc filter, that many non-technical visitors formed and held tenaciously to the idea that the gold was in suspension in the cyanide solution, and the zinc was used merely because of its durability. Improvements in detail were made in the direction of increasing the surface and decreasing the weight of the zinc, till now we have it in threads, 1 pound of which occupies about two gallons measure. The zinc in this form is possessed of enormous chemical activity, of which the strongest and most direct evidence is the fact that it burns in the air like thin shavings of wood. When the gold has been deposited, it is necessary to separate it from the excess of zinc present. The filiform structure of the zinc, and the exceedingly fine powder, as which the gold is deposited, render this an easy matter.

The filiform mass of zinc with gold powder adhering is vigorously shaken in water, when the gold falls off, and the fibrous particles of the zinc may be collected in a sieve. The gold settles easily, is collected, and fused directly into bullion.

Having now described the chief points in the process from the technical standpoint, let us look at the purely chemical aspect it presents. Reference has already been made to the fact that a cyanide solution acts on the gold in ores in preference to the sulphides of base metals with which it may be combined or associated; this selective action is the keystone of the whole process. It is known that metallic gold is dissolved by a cyanide; it is also known that sulphides of copper, zinc and iron artificially prepared are readily acted on by a cyanide solution; but we found a very different state of affairs in treating ores where these or similar compounds exist prepared by the hand of nature herself. Nature seems to render the base metallic compounds insoluble, while the gold combined with or contained in them is more easily acted on than the metal itself. This at once raises the question—how does gold exist in base refractory ores, is it combined or free? This question I admit I cannot answer satisfactorily to myself. Judging from theoretical considerations only, I think gold should exist almost invariably in the free state, for if we assume that sulphides, pyrites, etc., were formed by deposition from aqueous solution, the gold would be deposited in the metallic state. This may be shown by dropping some powdered pyrites into a solution of chloride of gold, when gold will be precipitated as metal; on the other hand, let us assume that the pyritous formations carrying gold were formed by igneous agency, in this case the gold ought to be metallic, too, because any sulphide of gold already existing would be decomposed by the high temperature, and of course sulphide of gold cannot be formed at a high temperature. It is true that sulphide of gold may combine with an alkaline sulphide and resist decomposition by heat, but such a combination as a matter of fact does not occur in nature. Telluride of gold, and I think, antimonide of gold are not decomposed by heat, but they occur in small quantities only and do not effect the general argument. In spite of these theoretical considerations, however, we have strong evidence to show that gold exists in several different states of combination or molecular structure. Let me give one case in illustration. A sample of tailings from the ordinary process of stamping and amalgamation was received, and I think it may safely be assumed that the mercury had extracted some gold from the ore which produced these tailings. We treated the finely ground tailings by alkaline solution of bromine, which extracted a considerable portion of gold, and the bromine treatment was repeated time after time till it ceased to extract gold; then it was treated with a hot solution of ferric bromide which yielded a further quantity of gold. This treatment was repeated time after time till it ceased to extract gold, and finally the residue of tailings was smelted and a still further quantity of gold produced. As this ore yielded its gold in stages to the four different processes of amalgamation, treatment with bromine, treatment with ferric bromide and smelting, we infer that the gold existed in four different states, mechanical or chemical. Notwithstanding the complex nature of these tailings, which consisted of all sorts of sulphides with the four-fold gold, the cyanide acted on it almost perfectly, extracting 93 per cent of the precious metal, whilst the higher extraction by any of the bromination methods was about 40 to 50 per cent. The cyanogen seemed to have an affinity for gold and a power of penetration so much stronger than mercury of bromine, that it broke through barriers impregnable to them and captured the gold.

Elsner has stated metallic gold dissolves in cyanide of potassium only in presence of oxygen. Not having seen the original account of Elsner's researches, I am not in the position to criticise his experiments, but I never could find that the presence of oxygen was necessary either to dissolve gold by itself or from ores by cyanide. If a piece of gold be immersed in a cyanide solution so that air to act on it would have to penesrate two inches or three inches of the solution, the gold will dissolve in its usual slow and steady fashion. The equation shows that either oxygen must be absorbed or hydrogen evolved. I have seen no evidence of the former, and can adduce no proof for the latter; but I think the latter the more probable, because I cannot conceive oxygen penetrating even a film of cyanide solution without at once oxidizing the cyanide to cyanate, whereas in the other case, as suggested to me by my friend Mr, Ellis, the nascent hydrogen may be at once seized by the excess of cyanide present and amoniacal compounds formed. However, we do not concern ourselves much with the reactions of pure gold, but as a matter of fact we cannot find that oxygen plays any part in the cyanide extraction of gold from ores. We have treated an ore with cyanide with free access of air, and then a parallel experiment was done with boiled water, the bottle filled to the stopper with solution and ore, and the stopper sealed. The extraction was the same in both cases.

We have so far only considered ores which are refractory from chemical as well as mechanical causes, but ores are frequently found in which the gold is refractory from a purely mechanical cause, which is the extremely fine division of the gold. The cyanide process is quite as applicable to this class of ore as to any other. These ores are generally spongy and absorbent, and this we find enables us to dispense with stirring the ore and cyanide solution together, the same end being accomplished by allowing this cyanide solution to percolate slowly through the mass—a clear saving in power.

The advantages claimed for the cyanide process over smelting and chlorination are—as compared with smelting, it requires no furnaces and no coal, and no fluxes, and thus may be used successfully in remote situations where smelting is utterly impossible. As compared with chlorination, cyanide process involves no roasting, therefore no furnaces and no fuel. Moreover, by the cyanide process, ores containing lead, zinc or earthy carbonates which cannot be worked to profit by chlorination, may be as easily and profitably treated as any other. For chlorination, about 7 per cent of the weight of the ore to be treated often has to be carried to the ore in the form of bleaching-powder, say 1½ per cent, bisulphate of soda 2 per cent, and sulphate of iron 2½ per cent, with packing, say, of 1 per cent, whereas about 1 per cent of the ore to be treated will cover the weight of the necessary cyanide, zinc and packing. Thus, by chlorination, one ton of chemicals will treat only about fourteen tons, whereas by the cyanide method one ton will treat 100 tons.

Moreover, chlorination does not extract any silver, but by the cyanide method the most of the silver—invariably associated with gold in ore is extracted along with the latter metal at the same operation. For the sake of simplicity I have not named silver in the body of this paper, but the remarks made in reference to gold generally apply to the silver associated with it.

From what I have seen of gold mines and gold mining in the Sierra Nevada, in the Rocky Mountains, in the Southern States of America, in Nova Scotia, from the many kinds of ore I have seen from all parts of the world, and from what I know of the selective and energetic action of cyanides, I confidently predict that cyanide of potassium, hitherto used only to polish amalgamated plates, will take a front rank as chief agent in gold extraction.

For further particulars of the MacArthur-Forrest process, write to

T. L. WISWALL,
Gen'l Mgr. and Sec'y,
P. O. Box 926.

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